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Research Article

Fabrication and Analysis of Micro Contact Based Probe Cell for IC Testing

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Abstract: This study presents the fabrication process and analysis of micro contact probe cell for IC testing deposited by dc sputtering technique on a glass substrate. It is designed to solve and replace pogo pins in IC testing process. In previous study, the new model of test socket with new materials in different shapes were designed by using ANSYS as Finite Element Analysis (FEA) software and the best parameter were obtained. According to the optimized parameters, prototype structures of the micro-contacts are fabricated using DC Sputtering with materials like copper and tungsten on base copper on glass substrates. Micro contact with thickness of 2800-7000 nm were successively deposited on glass substrate at sputtering power of 125 W in argon ambient gas with pressure of 10-15×10^{-3} Torr at a room temperature. The structural and electrical properties of micro contact were investigated by using profilometer, Scanning Electron Microscopy (SEM), Atomic Force Microscopy (AFM) and four point probes. Results show that the film thickness increased as the deposition the time getting longer. The Root Mean Square (RMS) roughnesses obtained are all in a good quality. On the other hand, the resistivity of micro contacts was less than 4 uΩ-cm, which has good conductive properties. Consequently, this design is appropriate for replacing the conventional pogo pin based testing tools.

Keywords: DC sputtering deposition, micro contact, pogo pin, test socket

INTRODUCTION

Semiconductor manufacturing includes many processes that impose high influential effects on the end product. These manufacturing processes include assembly process (wafer cutting, die attach, wire bonding for conventional chipsets or flux and reflow and under-fill process for flip-chip) and then followed by molding and package singulatio. After packaging process end, all electronic devices will be tested to make sure that all the required connection and performance are fulfilled.

At present, Pogo Pins are used as electrical connection between IC lead and load board. Pogo pins caused different problems including indentation marks, blur marks, tilting, spring malfunction, high maintenance cost and etc., (Amin and Lam, 2008; Teng *et al*., 2007). The present miniaturization trends towards higher performance, smaller and lighter product have resulted in an increasing demand for smaller pitch size and increase the issues of testing process with pogo pins. Pogo pins induced reliability problems when dealing with fine-pitch (<0.5 mm) packages. New electrical conductive cell was designed in previous works (Amin *et al*., 2009). It was based on micro-structures instead of pogo pins and consists of three different parts including polymer, metallic micro contactors and liquid metal. New Model was designed for QFP packages with 0.5 mm pitch size using simulation in previous years. Novel test socket mechanical design and analysis were successfully done by previous study. New models with new materials in different shapes were designed and the best one was achieved (Ehtiatkha *et al*., 2011).

This study presents the fabrication of micro contact which is one part of the conductive cell and its characterization. Finally, the completed fabricated micro-contacts are tested for verifying its sensing response and characterization.

MATERIALS AND METHODS

Sputter deposition mask: The deposition mask is made of stainless steel 304 material, which the openings on the mask surface enable the vaporized material (which is through sputter deposition in this case) to be condensed upon a substrate with desired patterns. When the deposition is completed, the mask is then removed, along with those unwanted material deposited on the mask's surface to reveal the pattern d

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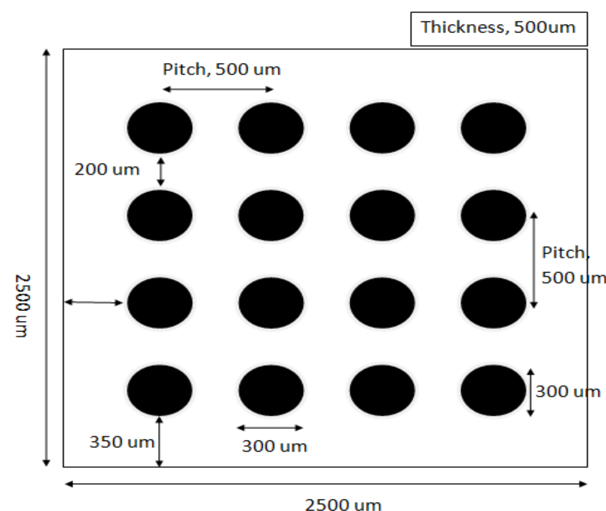


Fig. 1: The parameter for mask (diameter, pitch, thickness and space between each other)

Table 1: Parameters for the micro-contact sputtering deposition

Sample label	A1	A2	A3	A4	B1
Cu base thickness (um)	2.7	2.7	2.7	2.7	2.70
W thickness (um)	0	0.0	0.0	0.0	0.27
Micro contact columns height (um)	1	2.2	3.2	4.3	1.00
Total thickness (um)	2.8	4.9	5.9	7	2.97
Rotation (RPM)	1.0	1.0	1.0	1	1.00
Sputter type	DC	DC	DC	DC	DC
DC power (watts)	150	150	150	150	150
Deposition rate (A/sec)	~3	~3	~3	~3	~3
Deposition time (h)	1	2	3	4	1+0.5 (W)
Base pressure (Torr×10^{-3})	12-13	15	15	15-16	11-13
Initial temp (°C)	25	21	27	23	25
Final temp (°C)	40	45	55	48	40

Fig. 2: The image of actual mask used for making micro contact column

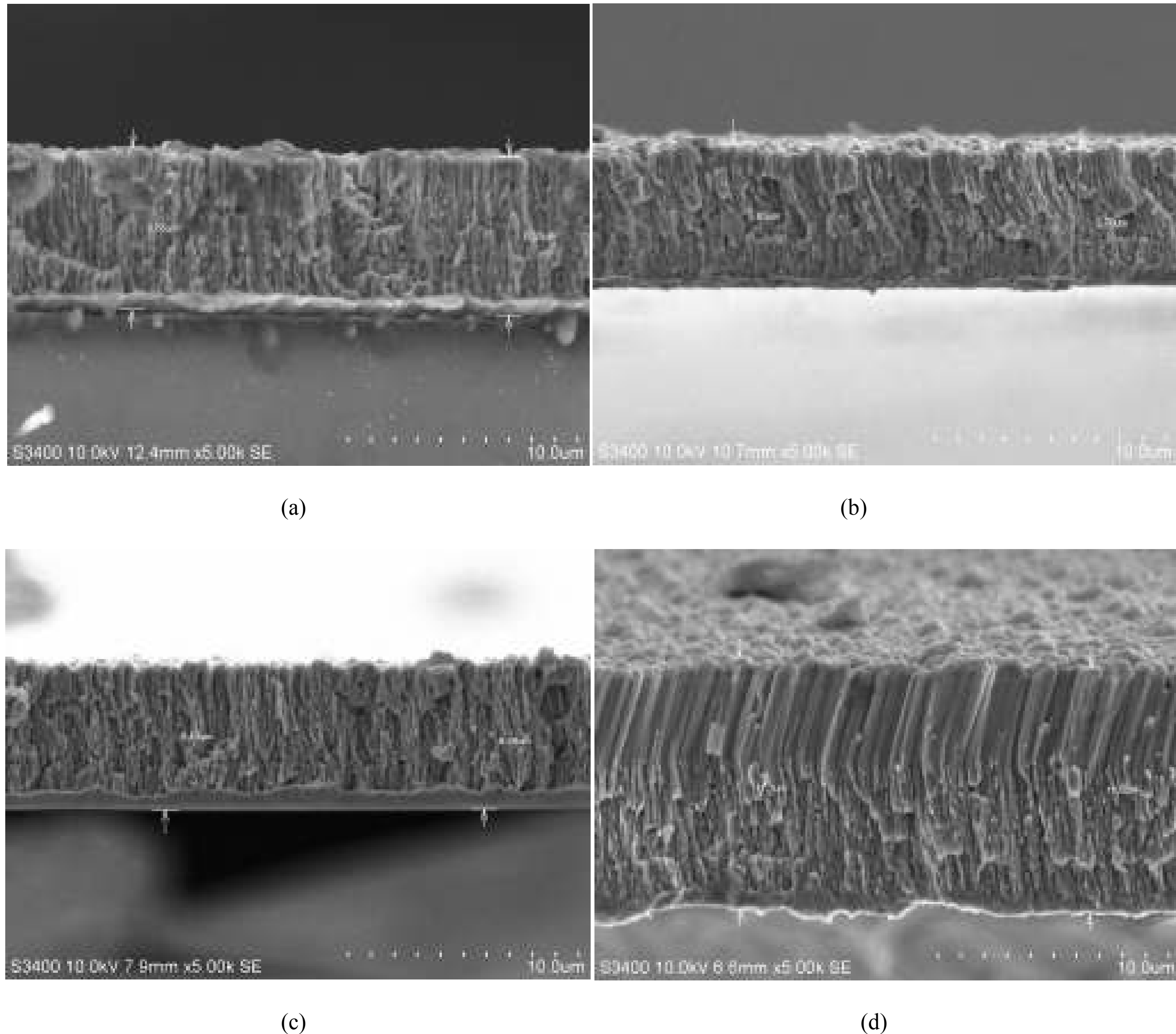
wanted to be deposited. The mask gives micro contact's column patterns on the substrate. The simplifie deposition mask drawing and its parameters are shown in Fig. 1.

The mask is having round openings arranged in square are used to deposit the micro-contact columns. The actual mask used is shown in Fig. 2. However, due to the limiting factors such as research budget (high-precision mask machining is very expensive), mask cleaning process complexity and the absent of deposition mask alignment equipment, the pattern openings on the mask is made ten times bigger than the original design. If given high-precision mask and mask alignment equipment, the same technology and methodology described for the proposed micro contact design can be applied to the original size.

Table 1 shows the sputter deposition parameter for micro contact. The built-in thickness-monitoring module (quartz crystal thickness monitor) monitors the thickness of the deposited material. The sputter deposition system will stop depositing when the desired thickness is achieved. The vacuum chamber is being vacuumed to the base pressure in the order of 10-15×10^{-3} Torr by running the turbo-molecular pump. All the sputter deposition is run under DC power of 150 Watt and the substrates' initial and final temperature are recorded. The substrate final temperature increased without being heated by the substrate holder. This is mainly due to the heat transfers from the magnetron gun and the plasma to the substrate. Five sets of samples were deposited, four set of micro contact with different height (A1, A2, A3 and A4, respectively) and one micro-contact coat with tungsten layer (B1).

RESULTS AND DISCUSSION

Physical or structural properties of the samples were characterized using Scanning Electron Microscopy (SEM) and Atomic Force Microscopes (AFM) while four point probes was used to characterize the electrical properties.



(a) (b)

(c) (d)

Fig. 3: SEM analysis on thickness of micro contact's base layer for (a) sample A1, (b) sample A2, (c) sample A3, (d) sample A4

Analysis of base layer of micro contact: Figure 3 shows the thickness of micro contact's base layer from SEM analysis. The base layers of micro contact were deposited at the same condition that gives almost the same thickness for all samples which is ~6 um.

Thickness of micro contact column: In this analysis, SEM was used to see the growth of micro contact column after the process of deposition using mask were done. Figure 4 showed the surface topography of micro contact for sample A1, A2, A3 and A4, respectively.

From these result, the structure of micro contacts deposited on base layer of cooper were clearly observed. Theoretically, the micro contact height or thickness increase linearly with the deposition time. However, there are a few factors like shadow effect that has given some influence to the thickness of micro contact thickness. The thickness of the micro-contact columns on different samples measured by dektak profilometer are indicated in Table 2.

Table 2: The measured thickness of micro contact column from dektak profilometer (Idris *et al*., 2014b)

Sample	Avg. u-contact height (um)
A1	0.23
A2	0.43
A3	0.94
A4	0.74
B1 (include W)	0.24

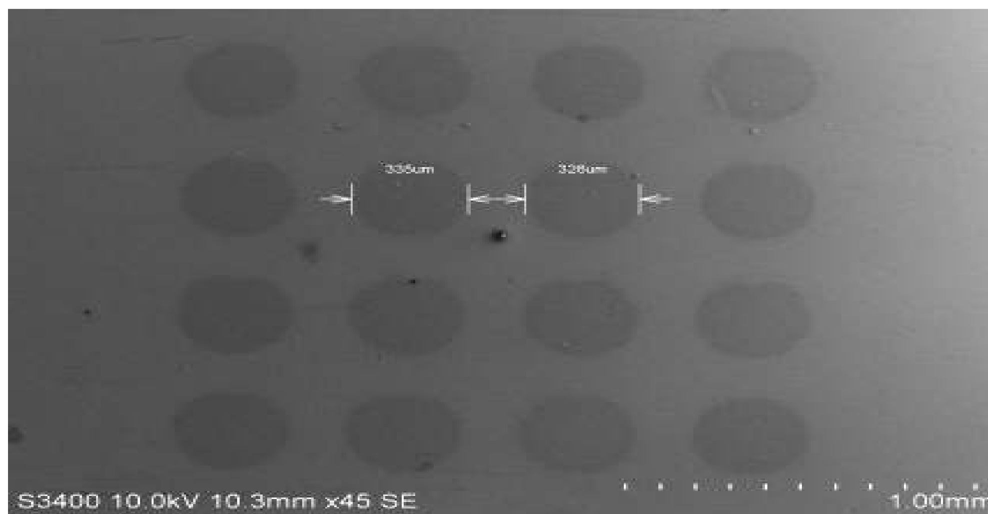
Avg.: Average

Micro contact diameter (SEM): The measurement of the micro-contact columns' diameter is also possible under inspection of the SEM. The SEM micrograph was taken from top view. SEM micrograph of micro contact column's diameter for sample A1, A2, A3, A4 and B1 are shown in Fig. 5 respectively. The diameter of the micro-contact columns on different parts of the

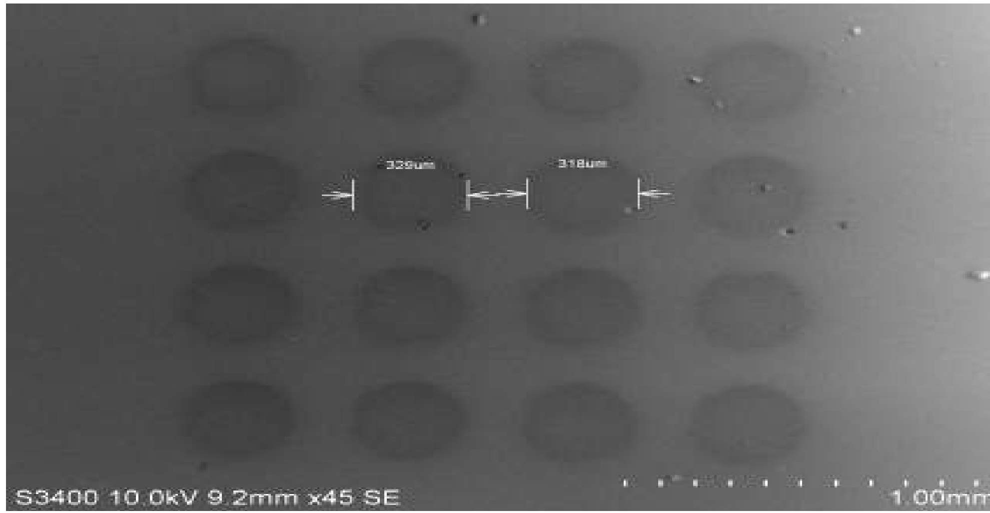
(a) (b)

(c) (d)

Fig. 4: SEM micrograph (tilt view) showing the surface topography of micro contact for (a) sample A1, (b) sample A2, (c) sample A3, (d) sample A4



(a)



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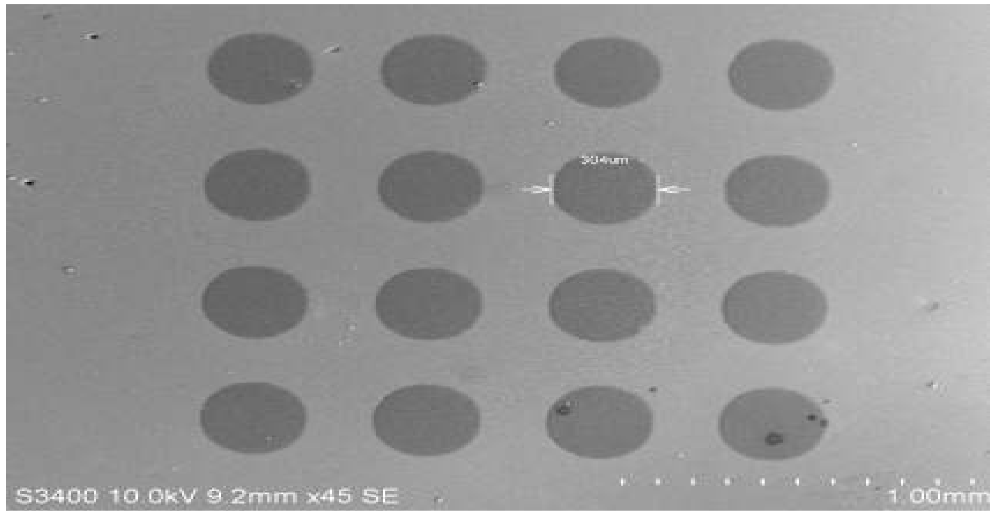

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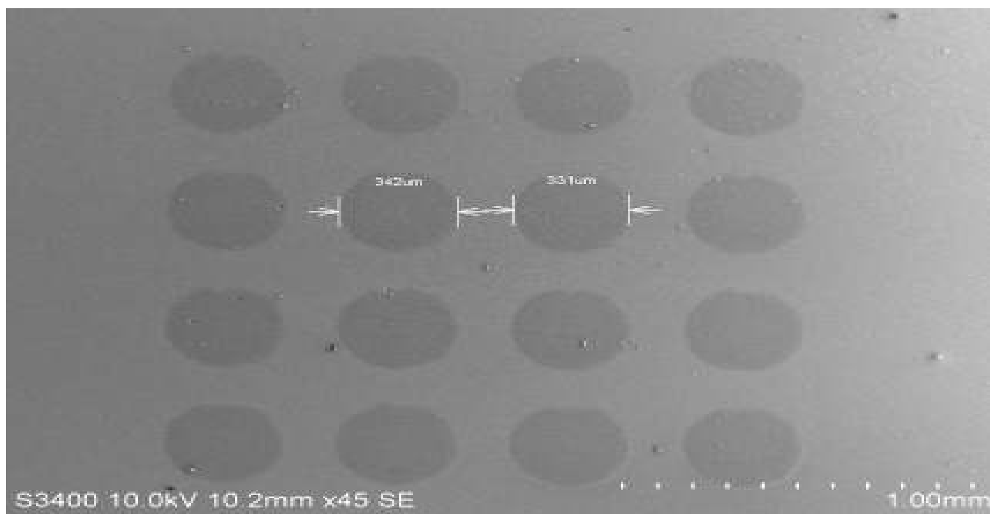

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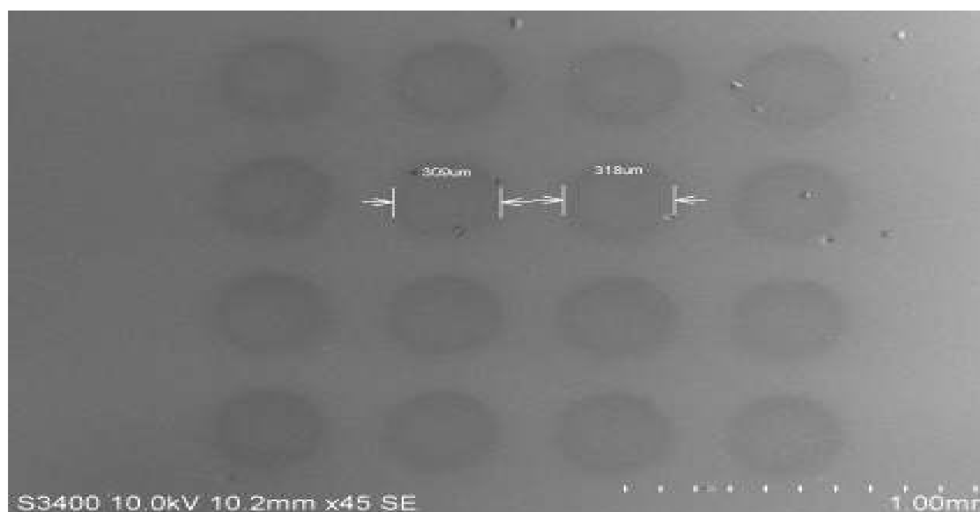


(e)

Fig. 5: SEM micrograph showing the diameter of micro contact column for samples, (a) A1, (b) A2, (c) A3, (d) A4, (e) B1

Table 3: Diameter readings of micro-contact columns from SEM

Sample	Magnification	Avg. micro-contact column diameter (um)
A1	X45	330.5
A2	X45	323.5
A3	X45	304.0
A4	X45	336.5
B1	X45	313.5

Avg.: Average

sample are listed in Table 3, which also stated the magnification used.

Surface structure and roughness of micro contact column (circle area): It is important to know the surface feature as it imply the quality of the deposited samples. Since all the parameters for each sample are the same except for the deposition time, the variation of the surface characteristic might response to the thickness of micro contact (Idris *et al*., 2014a). The AFM results illustrating the 2-D surface structure of micro contact column (circle area) in window area of 1×1 um is shown in Fig. 6 for sample A1, A2, A3 and A4, respectively. From these micrographs, small numbers of agglomerated grains have been observed.

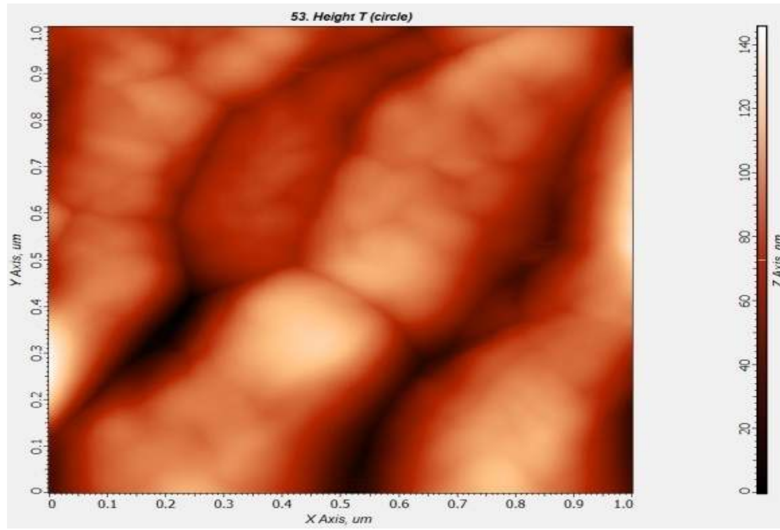
Based on data from profilometer and result from AFM, the surface roughness of micro contact column for sample A1, A2, A3 and A4, respectively are correlated with the micro contact column thickness as in Fig. 6 for window area of 1×1 um^2. As a whole, the surface roughness of each micro contact column is below than 25 nm which is showing that the samples have a good quality.

Comparison of between micro contacts coated with and without tungsten layer: Comparison of micro contact column's (circle area) surface roughness between micro contacts coated with and without tungsten layer.

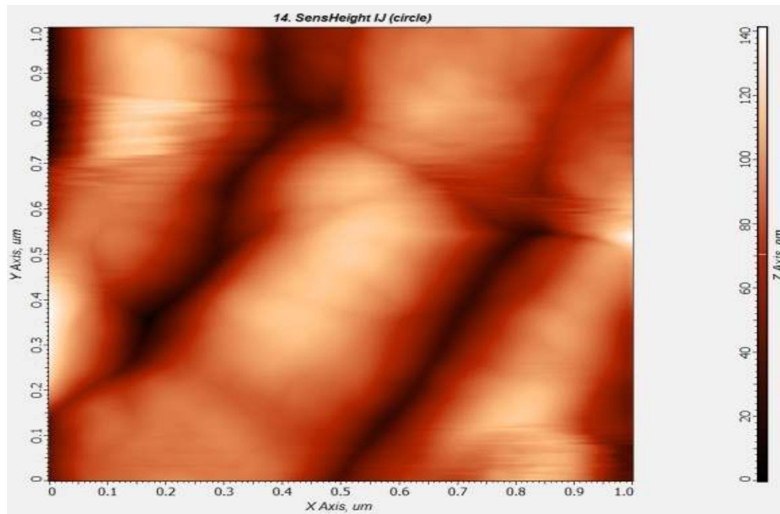
The comparison of surface roughness of micro contact columns between micro contact coated with and without tungsten layer was also examined. The result as in Fig. 7 showed that micro contact coated with tungsten layer (sample B1) has smoother surface roughness. This is happened because the thickness of tungsten layer covered the micro contact of sample B1 is just 310 nm which has smaller and less definable grains that produce smoother surface roughness or in other word the grains grow with increasing film thickness.

The comparison between micro contact coated with layer of tungsten (W) and without layer of tungsten has been done. The motive of this comparison is to see the effect of coating micro contact with other material like tungsten which one of the hardest material in this world to the electrical resistivity of micro contact. Both of these micro contacts have same features where all of fabrication processes were done in same parameters includes the thickness of micro contact column. The different is just at the last stage after the fabrication process finished, where micro contact of sample B1 was sputtered again with same process but using tungsten as target. The result show that sample B1 was successfully coated by 310 nm layer of tungsten.

From the graph in Fig. 8 showed that micro contact coated with layer of tungsten (W) gives lower resistivity compare to the micro contact without layer of tungsten. The resistivity may decrease because of the increment in micro contact layer where sample B1 is thicker than sample A1. Besides that, the tungsten rusts slowly by nature which makes it ideal in long-run operation and by coating micro contact it will make micro contact properties change. However, with only



(a)



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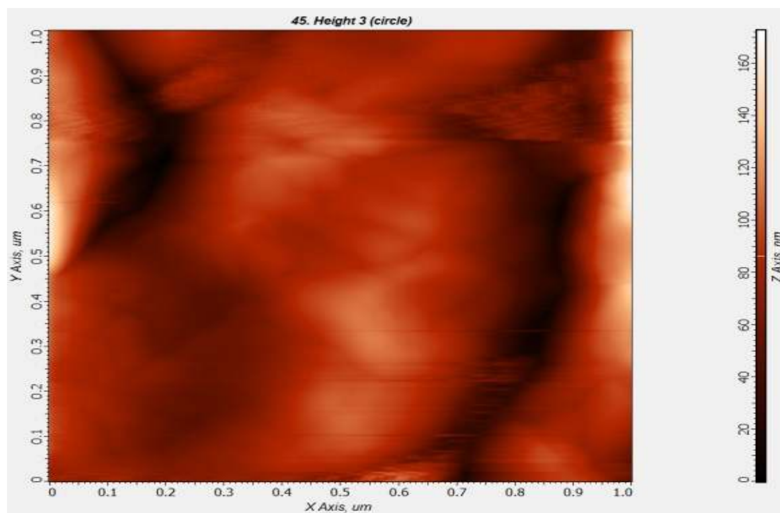

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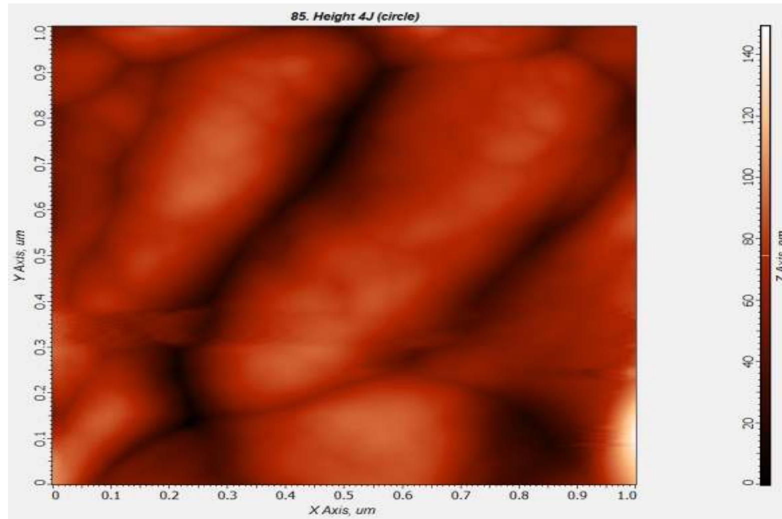

(d)

Fig. 6: AFM results with area window 1×1 um^2 for sample, (a) A1, (b) A2, (c) A3, (d) A4

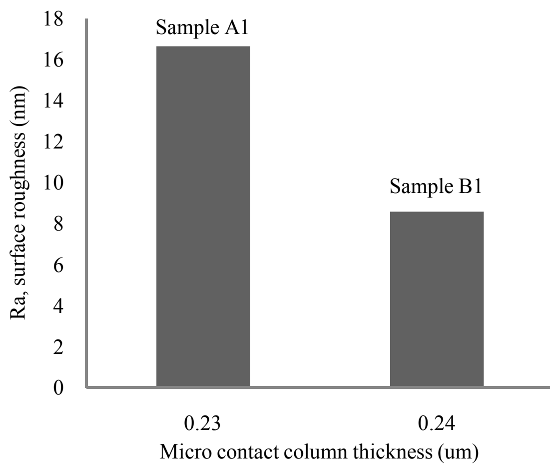

Fig. 7: Comparison of surface roughness between micro contacts coated with and without tungsten layer

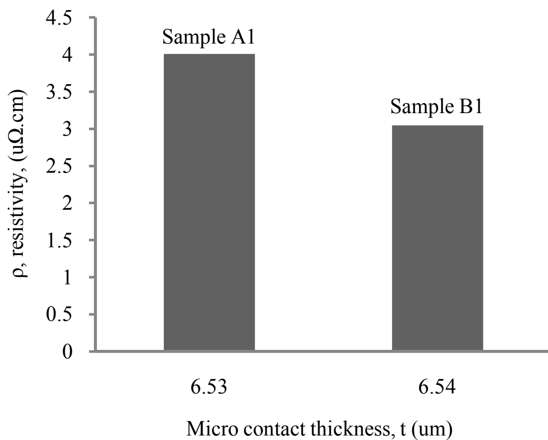

Fig. 8: Comparison of electrical resistivity between micro contacts coated with and without tungsten layer

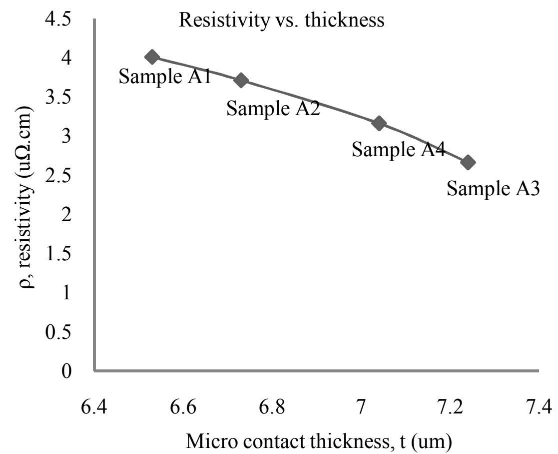

Fig. 9: Relationship between resistivity and thickness of micro contact

using one sample as comparison and the micro contact thickness is not too significant, nothing much can be concluded here. In the future, more samples with significant micro contact thickness can be done to analyze the resistivity of the micro contact coated with tungsten layer.

Resistivity of micro contact: The 4-point probe was implemented because electrical resistance is one of the most important properties for micro contact. Electrical resistance is one of the most important properties for micro contact. Electrical contact with high electrical resistance will gives inaccurate testing results during IC final testing, not to mention higher heat dissipation and impedance mismatch problems. The electrical properties of micro contact with different thickness ranging from 6.3 to 7.3 um were investigated. Here, the

resistivity of micro contact column and base are assumed to be same because all the fabrication processes and parameters are same. The measured resistivity over thickness is plotted in Fig. 9 by using equation as shown below:

$$\rho = 4.53\ (V/I) \times t \text{ where, } t = \text{base} + \text{column} \quad (1)$$

The results showed that the micro contact resistivity is decreases with the increase of samples thickness which obeys the law of resistance.

The surface morphology and structure of deposited copper influence the electrical properties micro contact. As the deposited film getting thicker, the grains of the material are also getting larger. The larger grains might contribute to the lower electrical resistance of the sample. This is because larger grains reduce the collision of scattering electron at grain boundaries and thus, it increases the electron mobility for the deposited film. Eventually, the resistivity of thick micro contact is reduces. This scattering also may happen due to the defects including vacancies, impurity atoms and dislocations exist in the film.

CONCLUSION

Pogo pins caused different problems including indentation marks, blur marks, tilting, spring malfunction, high maintenance cost and etc. Novel test socket mechanical design and analysis were successfully done in previous study. New models with new materials in different shapes were designed and the best one was achieved. The micro-contact have been fabricated by using sputtering deposition according to the design proposed in this study and the micro contacts physical and electrical properties were characterized by Scanning Electron Microscopy (SEM), Atomic Force Microscopy (AFM), profilometer as well as four-point probe. All the obtained results show the potential viability to solve the limitation of the pogo pin based testing tools by replacing them with the new novel IC test fixture as demonstrated in this study. From SEM, as the deposited film get thicker, the micro contact column can be observe clearly. Moreover, the grains of the material also getting bigger as the thickness increase. This increased grain size is believed to contribute to the film's lower electrical resistance as it increases the mobility of the charge carrier by reducing the grain boundary scattering. Dektak thickness profilometer showed that the micro-contact columns were formed with the desired column shape which is ideal for oxidation layer penetration and the highest micro contact thickness achieved was 0.94 um. Analysis from Atomic Force Microscope (AFM) showed that the surface roughnesses of the micro contact columns are not exceeding 100 nm which is showing that the samples have a good quality. Finally, it was found that the resistivity of micro contact is decreased with the increment of micro contact thickness in range of 2-4 uΩ.cm which is a good properties for probe cell.

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